Investigation into the Design of Broadband Singly-Fed Electromagnetically Coupled Patch (EMCP) Antenna Elements and Arrays for Circular Polarisation

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A Thesis Submitted for the degree of

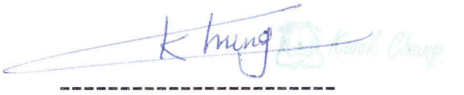
Doctor of Philosophy

November 2004

Statement of Originality

I hereby declare that this thesis has not previously been submitted for a degree nor has it been submitted as part of requirements for a degree except as fully acknowledged within the text.

I also certify that the thesis presents my own work and has been written by me. Any help that I have received in my research work and the preparation of this thesis have been acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.



Kwok L. Chung

Dedication

To Fiona, Summi and Michelle,

for their love and patient

Abstract

The rapid development of satellite and wireless communications pose extraordinary demands on broadband circularly polarised (CP) antenna elements and high-performance antenna arrays. The use of high-dielectric-constant materials as the substrate for the driven layer and a low-dielectric-constant material as superstrate for the radiating patch overcomes the conflict between circuit integration and antenna radiation. The aim of the research presented in this thesis is to design and develop high performance singly-fed microstrip patch antennas and arrays for CP applications.

Firstly, we introduce a singly-fed cross-aperture coupled patch antenna and a stacked patch antenna using *high* and *low* dielectric materials known as *Type-F* and *Type-E* elements, respectively. As the physical structure of the *Type-E* element is close to the conventional linearly-polarised electromagnetically coupled patch (LP-EMCP) antennas, we have also denoted it as CP-EMCP antenna. The development of CP-EMCP antennas addresses the drawbacks of the cross-aperture patch antenna. A systematic optimisation method is developed for the design of CP-EMCP elements, at which the mean frequencies of the bandwidths can be adjusted in order to achieve a wide overlaid bandwidth. Secondly, we investigate the effects of perturbation on the

parasitic patch, layer displacements, material tolerances and superstrate thicknesses on the broadband performance as well as the mutual coupling of the CP-EMCP elements. Both our theoretical and experimental results show that the CP-EMCP elements are robust in performance and have a low mutual coupling. When compared to the conventional stacked EMCP antennas and to the reduced surface-wave antenna, the mutual coupling between CP-EMCP elements is lower which allows the use of small element spacings to avoid grating lobes, which therefore make these elements good candidates for high-performance CP arrays.

Following a parametric study on the effect of displacements between stacked patches and the loss consideration of the coplanar feed network printed on high dielectric constant substrates, the *modified Type-E* elements whose parasitic patch have a zero perturbation are developed for the design of high performance CP arrays. The low mutual coupling allows short feed-lines to connect with the spatially offset elements so as to minimise the feed loss. Consequently, it became possible to develop the novel sequentially rotating feed networks which incorporate the modified elements with a small element spacing of $2/3\lambda_o$ for the 4- and 16-element planar antenna arrays. The results indicate that these arrays have high gain, low axial ratio, high antenna efficiency low sidelobe levels, and wide overlaid bandwidth.

Acknowledgements

A thesis like this, contains more than *four* years of research work, does not get written successfully without the faith, advice, support, criticism, and help by people around me, and organisations in supplying or allowing to use many expensive microwave materials and equipment. The following organisations and people are gratefully thanked for their contributions towards this thesis:

The Commonwealth Department of Education, Science and Training, Australia: for the three and half years Australian Postgraduate Award (APA) scholarship, without their financial support this research work would not exist.

Cooperative Research Centre for Satellite Systems (CRCSS): for the 3 years top-up on my APA scholarship, without that I have to do more teaching duties. Thanks also to Dr. Andrew Parfitt, for his technical comment and advice.

ICT Centre at CSIRO: Dr. Trevor Bird, Kieran Greene, Steve Barker, Ken Smart and Li Li, for allowing the use of their indoor chamber for antenna measurements, and their friendly technical support and advice.

Artronic Productions (Australia) Pty. Limited: Ken Wales and his production team, for their kind support and the efficient fabrication of patch antennas.

Rogers® Corporations: for the supply of many free samples of dielectric materials and technical advice.

GIL Technologies: for the supply of dielectric laminates in this research work.

Johnson Components: for the supply of free samples of SMA and SSMA connectors with the technical information.

A/Professor Ananda Mohan Sanagavarapu (A. S. Mohan): for his expert guidance, supervision and his commitment to produce high quality research output. I gratefully acknowledge his advice through all stages of my research, especially with regards to writing of my thesis and the technical papers during the years.

A/Professor Sam Reisenfeld: for his role as my co-supervisor and for providing encouragement and suggestions on my work. Thanks also to his financial support for the travel to the IEEE conferences.

Professors Rod Belcher and Hung T. Nguyen: for their leadership in the Engineering research and development at the UTS, and also for their support in maintaining my full scholarship in the last half-year.

Professor Roman Stere: a respected teacher from the subject of Data Acquisition and Distribution System (DADS), for his sincere help and advice.

Dr. Andrew R. Weily: a typical Oz hard worker and a real researcher, for his enthusiastic help, comments and discussions during my research work.

Dr. John Yong: a good English teacher and a friend of mine, for his proof reading of my writing.

Dr. Henry Zhang, Dr. K. K. Fung and Rosa Tay: for their perspicacious advice, discussions and friendship.

Dr. Venkat Ramaswamy and Dr. Andrew Mears: for giving me teaching duties in the Faculty of Engineering, UTS.

Dr. Heng Chiu, David Tang, Tony Huang, David Smith, S. Kandeepan, Jeffery Tsui, Thung Tran and **S. H. Lee:** a group of Telecommunications research fellows, who create a great research atmosphere at the Level 20, Building 1 of UTS, for their help, support, comments, criticism and friendship.

Mr. Ray Clout: for his kind of technical support in the Microwave Lab at UTS.

Richard Moor and Ron Smith: for their efficient fabrication of hardware and sound technical support. Their delicate skill made the experimental work so successful. Furthermore, thanks for allowing me to run wild in their Mechanical Workshop while chatting to music.

The Anonymous Reviewers: for their positive comments and suggestions on my IEEE Journal papers.

Finally, but not the least, I would like to express my appreciation to every member of the **Chung's family**: my parents, my brothers, sister, sister in-law, and my wife for their love and constantly support of my research work.

Publications

Materials presented in the core chapters (Chapter 2 to 5) of this thesis are also available in the following referred/published papers, which are the research output by the candidate during his four-year doctoral candidature at the University of Technology, Sydney.

Chapter 2

[C2.1] K. L. Chung and A. S. Mohan, "Gain and bandwidth enhancement of a 2.4GHz singly-fed cross-aperture patch antenna", *IEEE Antennas and Propagat., Society Intern Symp., Jun 2002,* San Antonio. Vol 1, pp. 410-413.

[C2.2] K. L. Chung and A. S. Mohan, "Techniques to increase gain and impedance bandwidth of a cross-aperture coupled patch antenna", *Microwave and Optical Technology Letters,* Vol. 37, No.4, pp. 283-286, May 2003.

Chapter 3

[C3.1] K. L. Chung and A. S. Mohan, "A broadband singly-fed electromagnetically coupled patch antenna for circular polarisation", *Proc WARS02, Workshop on the Application of Radio Science,* Sydney, Australia, Feb 2002.

[C3.2] K. L. Chung and A. S. Mohan, "Singly-fed circularly polarised patch antenna with wide impedance and axial-ratio bandwidth", *2002 IEICE Interim International Symposium on Antennas and Propagation.* Nov, 2002, Yokosuka Research Park, Japan Proc ISAP'02, pp. 275-278.

[C3.3] K. L. Chung and A. S. Mohan, "A systematic design method to obtain broadband characteristics for singly-fed electromagnetically coupled patch antennas for circular polarisation", *IEEE Transactions on Antennas and Propagation,* Vol. 51, No. 12, pp. 3239-3248, 2003.

[C3.4] K. L. Chung and A. S. Mohan, "An investigation into an antenna arrays composed of broadband circularly polarised EMCP elements at X-Band". *IEEE Antennas and Propagat., Society Intern Symp.,* Vol 2, pp. 868-871, Jun 2003, Columbus, Ohio.

[C3.5] K. L. Chung and A. S. Mohan, "Design of stacked circular/quasi-elliptical patch array for broadband CP applications" in Proceedings of *The 6th Intern Symp on Antennas, Propagation and EM Theory*, ISAPE'03, pp. 62-65, Oct 28-Nov 1, 2003, Beijing, CHINA.

Chapter 4

[C4.1] K. L. Chung and A. S. Mohan, "A broadband electromagnetically coupled patch antenna with robust characteristics against layer misalignments", in Proceedings of *IEEE Canadian Conference on Electrical and Computer Engineering, 2003.* CCECE'03, Vol. 3, pp. 1425-1428.

[C4.2] K. L. Chung and A. S. Mohan, "A study of mutual coupling between CP electromagnetically coupled patch antennas", in proc. of the *14th International Symposium on Personal, Indoor and Mobile Radio Communications,* PIMRC'03, Vol. 2, pp. 1889-1893, September 7-10, 2003, Beijing, CHINA.

[C4.3] K. L. Chung and A. S. Mohan, "Mutual coupling between singly-fed circularly polarised stacked patch antennas with various orientations" *Asia-Pacific Microwave Conference 2003*, Vol. 3, pp. 1856-1859, November 4-7, 2003, Seoul, KOREA.

[C4.4] K. L. Chung and A. S. Mohan, "The effect of offset patch on the broadband characteristics of an electromagnetically coupled patch antennas", *Microwave and Optical Technology Letters,* Vol. 38, No.5, pp. 345-348, Sep 2003.

[C4.5] K. L. Chung and A. S. Mohan, "Effect of superstrate thickness on the performance of broadband circularly polarised stacked patch antenna". *IEEE Antennas and Propag. Society Intern Symp.,* Vol 1, pp. 687-690, Jun 2004, Monterey, California.

[C4.6] K. L. Chung and A. S. Mohan, "Effect of dielectric material tolerance on the performance of singly-fed circularly polarised stacked patch antennas". *IEEE Antennas and Propag. Society Intern Symp.*, Vol 1, pp. 479-482, Jun 2004, Monterey, California.

[C4.7] K. L. Chung and A. S. Mohan, "Experimental study on the performance of circularly polarised stacked patch antenna against layer displacements", *2004 International Symposium on Antennas and Propagation.* Aug, 2004, Sendai, Japan, Proc ISAP'04, pp. 397-400.

Chapter 5

[C5.1] K. L. Chung and A. S. Mohan, "An investigation into an antenna arrays composed of broadband circularly polarised EMCP elements at X-Band". *IEEE Antennas and Propag. Society Intern Symp.*, Vol 2, pp. 868-871, Jun 2003, Columbus, Ohio.

[C5.2] K. L. Chung and A. S. Mohan, "Design of stacked circular/quasi-elliptical patch array for broadband CP applications" in Proc. of *The 6th Int. Symp. on Antennas, Propagation and EM Theory*, ISAPE'03, pp. 65-65, Oct 28 - Nov 1, 2003, Beijing, CHINA.

[C5.3] K. L. Chung and A. S. Mohan, "A circularly polarised stacked electro-magnetically coupled patch antenna", *IEEE Transactions on Antennas and Propagation*, Vol. 52, No. 5, pp. 1365-1370, 2004.

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List of Acronyms

ABC	Absorbing Boundary Condition
AR	Axial Ratio
ABW	Axial-Ratio Bandwidth
AUT	Antenna under Test
CF	Correction Factor
CP	Circular Polarisation
CP-EMCP	Circularly-polarised Electromagnetically Coupled Patch
CPG	Circular Polarisation Gain/Circular-gain
CW	Clockwise
CCW	Counter-Clockwise
EMCP	Electromagnetically Coupled Patch
EPA	Elliptical Patch Antenna
GBW	Gain Bandwidth
IC	Impedance Change
LHCP	Left-hand Circularly Polarised
LP	Linearly Polarisation
LPG	Linear Polarisation Gain/Linear-gain

OBW	Overlaid Bandwidth
RAB	Right-Angle Bend
RHCP	Right-hand Circularly Polarised
RL	Return Loss
RVWF	Rectangular Vector Wave Functions
SAR-RSW	Short Annular Ring-Reduced Surface-Wave antenna
SFCP	Singly-fed circularly polarised
SDA	Spectral Domain Approach
SGA	Standard Gain Antenna
SRA	Sequentially Rotated Array
SWR	Standing Wave Ratio
TJ	T-Junction
XACP	Cross-Aperture Coupled Patch antenna
XPD	Cross-polarisation Discrimination
ZBW	Impedance Bandwidth